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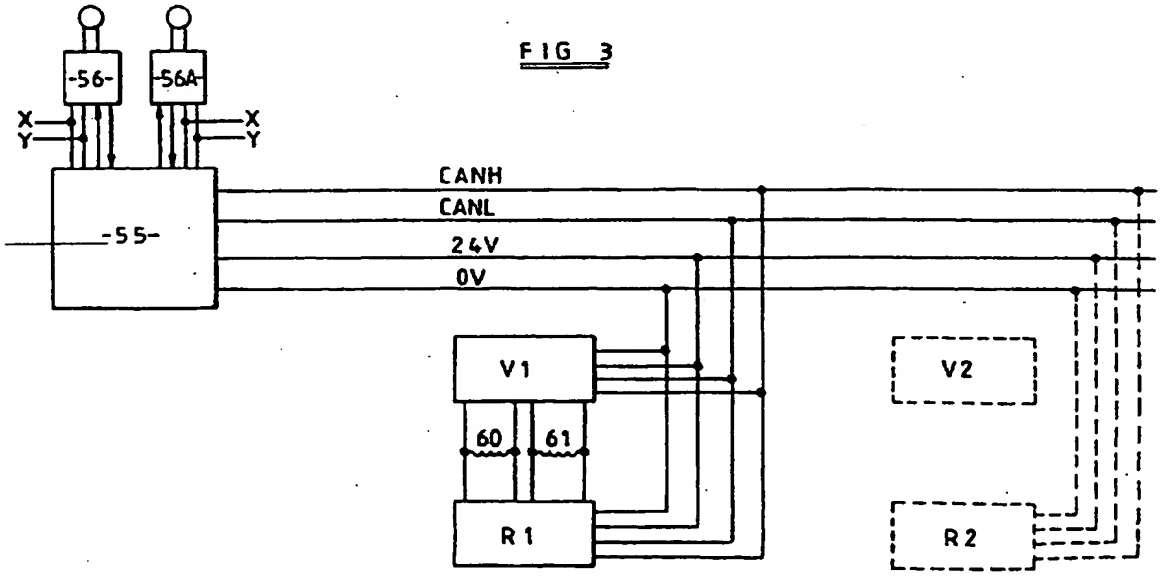
(54) Valve malfunction recovery system

(57) In an actuator control system eg the hydraulic system of a robot, an actuator is controlled according to the demand requirements input by the operator 56, 56a. When a malfunction condition is detected, limited operation of the actuator is permitted under the control of the operator to allow the system to be returned to a recovery condition.

FIG 3



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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

The print reflects an assignment of the application under the provisions of Section 30 of the Patents Act 1977.

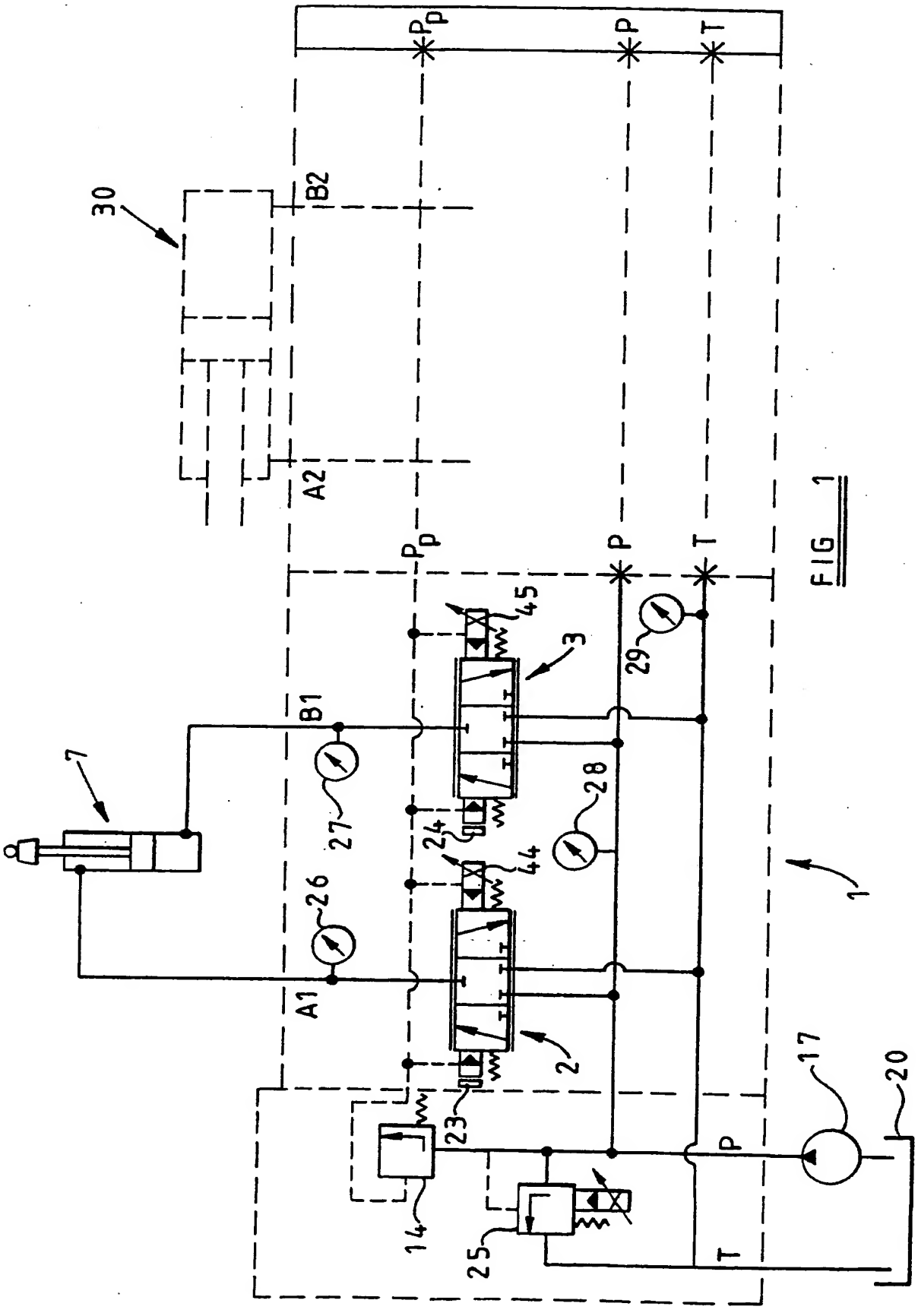

FIG 1

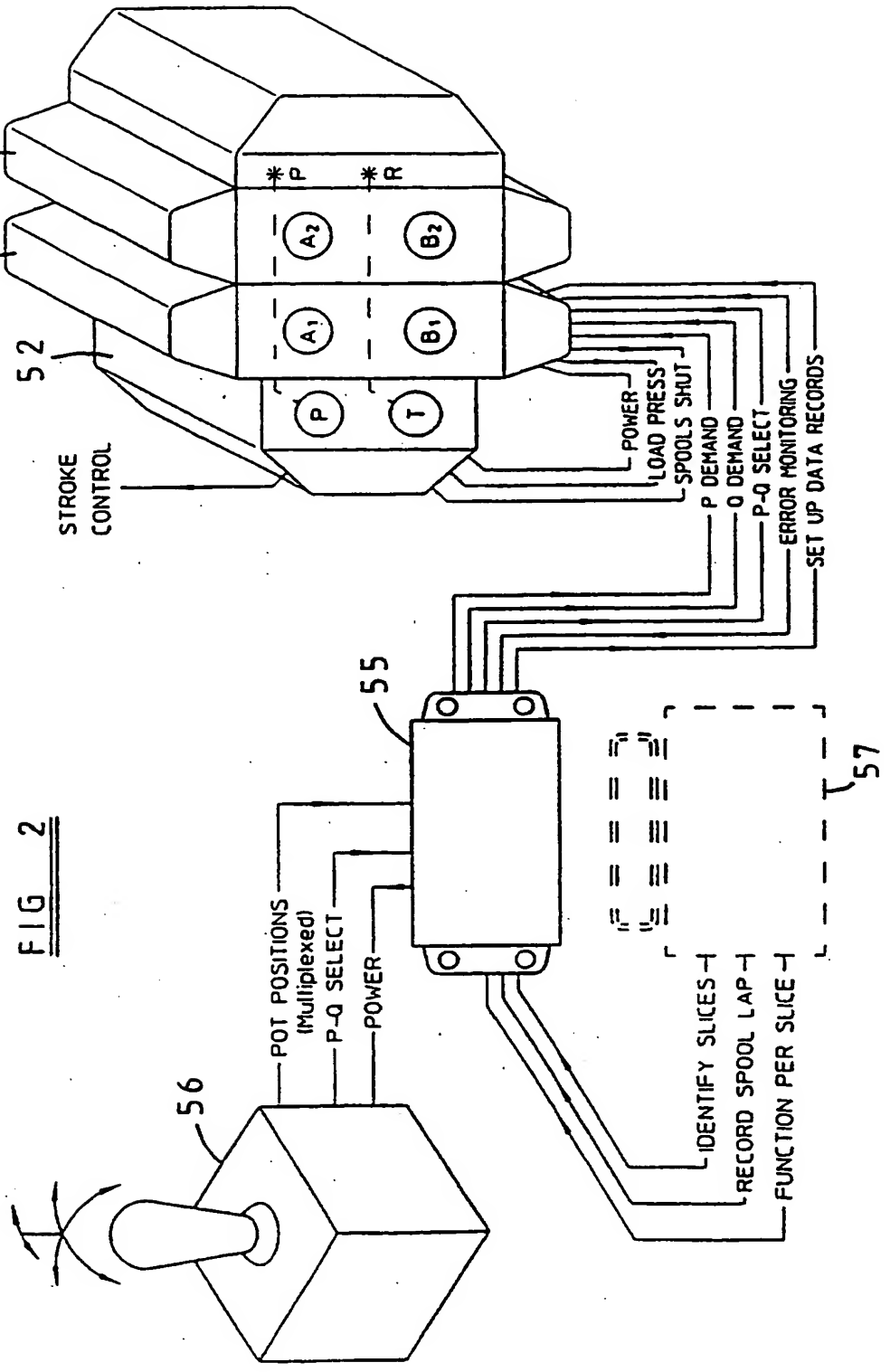
51
50
52
*P
*R
A2
B2
A1
B1
P
T
STROKE CONTROL
POWER
LOAD PRESS
SPOOLS SHUT
P DEMAND
Q DEMAND
P-Q SELECT
ERROR MONITORING
SET UP DATA RECORDS
55
57
POT POSITIONS (Multiplexed)
P-Q SELECT
POWER
56
IDENTIFY SLICES
RECORD SPOOL LAP
FUNCTION PER SLICE

FIG 2

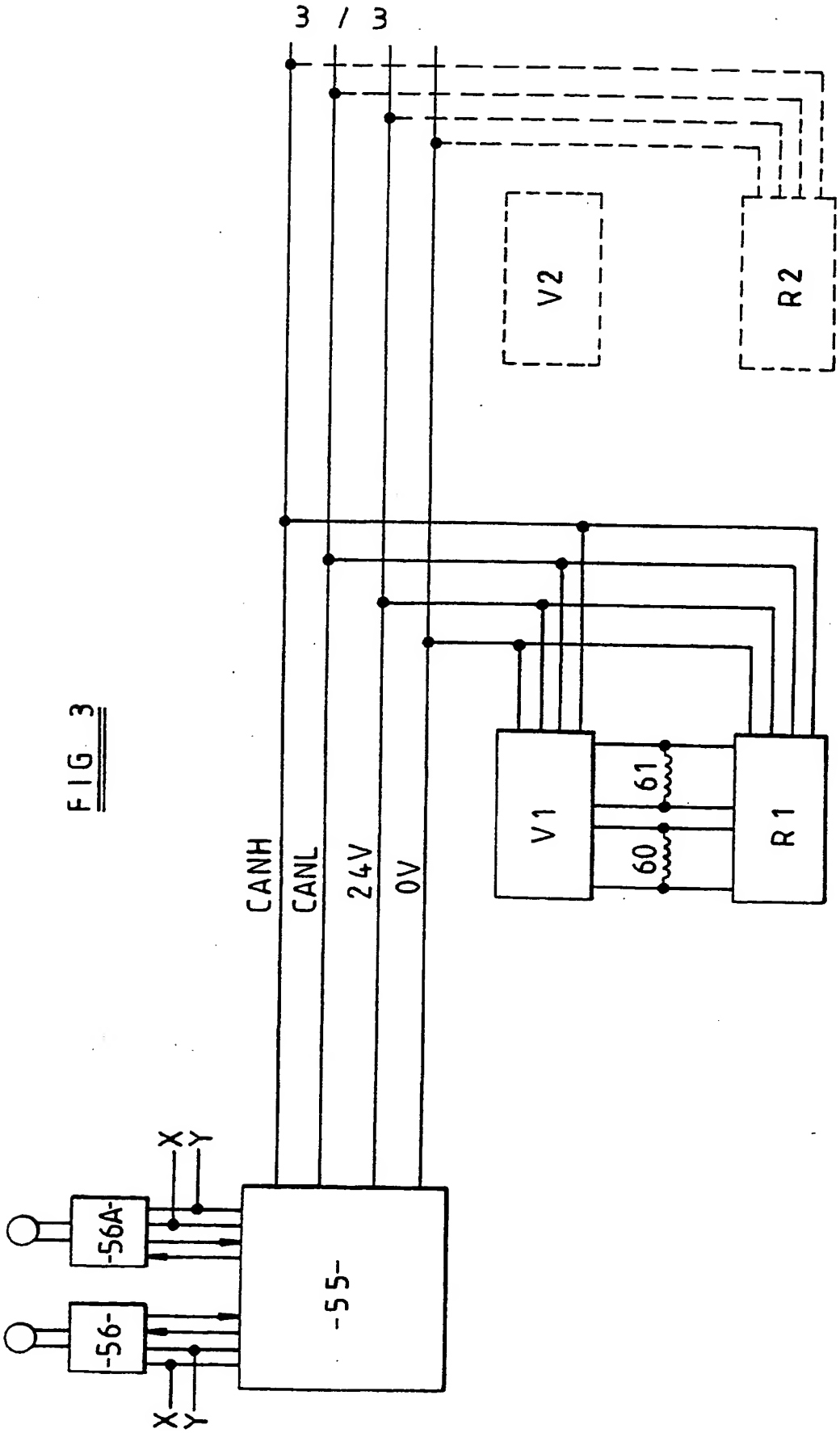

FIG 3

"Electronic Control Systems for Electrohydraulic Control Valve Assemblies"

This invention relates to electronic control systems for electrohydraulic control valve assemblies for controlling hydraulic fluid actuated devices.

It is known to utilise a proportional control valve assembly for controlling a fluid actuated device, such as a control ram for a lifting arm of an earth moving vehicle for example, in response to a demand signal supplied by an operator actuated joystick. Such a control valve assembly typically incorporates a main spool valve having a first actuating port for bidirectional fluid flow between the spool valve and a first port of the hydraulic fluid actuated device, a second actuating port for bidirectional fluid flow between the spool valve and a second port of the hydraulic fluid actuated device, a pump port for input fluid flow to the spool valve from a hydraulic pump, a tank port for outward fluid flow from the spool valve to a hydraulic tank, and a spool for controlling the direction and rate of fluid flow between the first actuating port and the pump or tank port and the direction and rate of fluid flow between the second actuating port and the pump or tank port.

British Published Application No. 2298291 discloses an electrohydraulic proportional control valve assembly comprising a first main spool valve connected to the first actuating port, the pump port and the tank port for controlling the direction and rate of fluid flow to and from the first actuating port of the hydraulic fluid actuated device,

and a second main spool valve connected to the second actuating port, the pump port and the tank port for controlling the direction and rate of fluid flow to and from the second actuating port of the hydraulic fluid actuated device. The first main spool valve has a first spool member which is movable to vary the throughflow cross-section for fluid flow to and from the first actuating port, and the second main spool valve has a second spool member which is movable, independently of movement of the first spool member, to vary the throughflow cross-section for fluid flow to and from the second actuating port. Furthermore the assembly includes position sensors for supplying electrical position signals indicative of the actual positions of the first and second spool members, and pressure sensors for supplying electrical pressure signals indicative of the hydraulic fluid pressures in the first and second actuating ports and the pump and tank ports. A servo control system is provided for controlling the positions of the first and second spool members in dependence on the electrical position and pressure signals and in response to the demand signal supplied by the operator actuated joystick.

Such an assembly incorporates control circuitry which can be programmed to provide a large number of control functions. For example, the flow rate and/or pressure at the ports of the hydraulic fluid actuated device may be controlled so that the device is adjustable at a uniform rate which is independent of the load, that is so that the rate of movement of the moving part of the device is not affected by variation of the applied load or supply pressure, either in a passive load condition or in an over-running load condition. Independent control of the flow rate and/or pressure at the two ports of the

hydraulic fluid actuated device is particularly advantageous as it enables operation of the device at a higher level of efficiency and safety than is possible with prior control arrangements in which efficiency losses are incurred as a result of the need to displace the moving part of the device against a back pressure. However there is a risk that, in the event of failure of a control circuit of the assembly, it may no longer be possible for the operator to operate the hydraulic fluid actuated device by means of the joystick, for example in order to place the lifting arm of an earth moving vehicle in a safety position.

It is an object of the invention to provide an electronic control system for an electrohydraulic control valve assembly which enables the hydraulic fluid actuated device to be placed in a recovery condition by the operator following malfunction of a control circuit.

According to the present invention there is provided an electronic control system for an electrohydraulic control valve assembly as defined in the accompanying claims.

In order that the invention may be more fully understood, a preferred electronic control system in accordance with the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a hydraulic circuit diagram of the electrohydraulic proportional control valve assembly in which the system is incorporated;

Figure 2 is a block diagram showing the electrical interconnections between

various parts of the assembly; and

Figure 3 is a block diagram of the electronic control system of the assembly.

Referring to Figure 1 the electrohydraulic proportional control valve assembly 1, which is described in more detail in British Published Application No. 2298291, comprises first and second spool valves 2 and 3 connected to first and second actuating ports A1 and B1 of a hydraulic fluid actuated device 7. The first and second spool valves 2 and 3 have spool members which are axially movable by pilot fluid flows controlled by electrically operated pilot valves 44 and 45 between end positions in which the spool member places the corresponding actuating port in communication with either a pump 17 or a tank 20. The fluid supply to the pilot actuator valves 44 and 45 is regulated by a pilot pressure regulator 14, and a pressure relief valve 25 is provided for venting the output of the pump 17 to the tank 20 when no pressure load is sensed.

The spool members of the spool valves 2 and 3 are movable to connect either port of the device 7 to the pump 17 or the tank 20 over a throughflow cross-section which may be varied proportionately between a minimum opening value and a maximum opening value, both spool members being spring biased towards their neutral positions (in which they are shown in Figure 1). Furthermore position sensors 23 and 24 are provided for supplying electrical position signals indicative of the positions of the spool members, and four pressure sensors 26, 27, 28 and 29 are provided for supplying electrical pressure signals indicative of the fluid pressures in the ports A1 and B1 of the

device 7 and the ports P and T connected to the pump 17 and the tank 20.

As shown diagrammatically on the right hand side of Figure 1, the pilot pressure regulator 14 may also serve to regulate pilot fluid supply to the pilot valves of a further pair of spool valves for controlling supply of fluid to a further hydraulic fluid actuated device 30. The two devices 7 and 30 may be two rams for controlling different linkage axes of an earth moving vehicle for example, and may be controlled by two valve slices in the assembly as described in more detail below.

Referring to Figure 2 the complete valve assembly comprises, for example, a bank of two valve slices 50 and 51 of the general form described, and an end slice 52 connected to the valve slices 50 and 51 and having a pump port P and a tank port T. The end slice 52 serves to control the supply pressure of hydraulic fluid from the pump in dependence on demand signals indicative of the demand for fluid to be supplied to the valve slices 50 and 51. During operator actuation the pressure relief valve 25 shown in Figure 1 is controlled in dependence on the load pressures sensed by the pressure sensors 26 and 27 to control the pressure of fluid supplied by the pump so that it exceeds the highest load pressure sensed by a predetermined amount.

Furthermore a control computer 55 is electrically connected to the valve slices 50 and 51 and to a joystick 56 by a serial communications network so as to monitor operator actuation of the joystick 56 and so as to supply to the valve slices 50 and 51

pressure (P) or flow (Q) demand signals and pressure-flow (P-Q) select signals. In addition the control computer 55 serves to supply initial set up data to the valve slices 50 and 51 on initial set up programming utilising a plug-in programmer 57, and also to provide error monitoring of the valve slices 50 and 51. The manner in which the control computer 55 is used to control the valve slices 50 and 51 is described in more detail in British Published Application No. 2298291, and it should be understood that the control logic for carrying out such control functions is incorporated in the valve slices 50 and 51 themselves and not in the control computer 55 which serves to provide overall system control. The control computer 55 supplies a pressure-flow (P-Q) select signal to each valve slice, and a selection is made by a selector in each valve slice in dependence on this signal as to whether pressure control or flow control is to be effected.

Figure 3 diagrammatically shows a recovery system which is incorporated in the control electronics in order to allow emergency operation of the hydraulic fluid actuated device in the event of failure of a microcontroller for controlling one of the valve slices. The recovery system comprises a respective recovery circuit R1, R2, etc. associated with each valve slice V1, V2, etc. and consisting of a small, low cost 8-bit microcontroller. In the system as shown the computer 55 accepts operator demand signals from two joysticks 56 and 56A for controlling the main control valves, and sends signals to the valve slices V1, V2, etc. to cause the valve control electronics to supply current to the two actuating coils 60 and 61 for driving magnetic actuators which in turn drive the two pilot valves. If the control electronics or software of one of the valve slices V1, V2,

etc. fails, the current to the pilot valve coils 60 and 61 is cut off by an internal monitoring system contained within the valve slice electronics, and in addition an error signal indicating the address or unique identifier of the valve slice which has failed is sent to the computer 55. The error signal is in the form of an appropriate "Valve n Failure" message, where n denotes the address or identity of the failed valve slice. If the failure of the valve electronics is such that the valve slice is unable to send an appropriate error signal to the computer 55, the computer 55 will itself quickly determine that the relevant valve slice has failed, since the control system requires that each valve slice sends regular identifying signals to the computer 55 identifying the address or unique identifier of the valve slice. The computer 55 monitors receipt of these regular identifying signals and determines the identity of a valve slice which has failed by sensing that receipt of identifying signals from that valve slice has ceased.

In the event of receipt of an error signal by the computer 55 or sensing by the computer 55 of failure of a valve slice by cessation of receipt of identifying signals from that valve slice, the computer 55 will execute a predetermined shut down sequence in order to place the system in a safe state. As part of this shut down sequence the computer 55 transmits a specific bit stream along the two CAN bus wires. The voltage levels of the recovery procedure (being single ended) differ from the normal CAN bus voltage levels (being differential) and are accordingly adapted to actuate the recovery circuits R1, R2, etc. The bit stream contains the address or unique identifier of the valve slice which has failed, and this will cause only the recovery circuit associated with the

failed valve slice to accept subsequent instructions sent by the computer 55 over the CAN bus wires. Such instructions sent in response to operator demand signals from the joysticks 56, 56A cause the recovery circuit of the failed valve slice to send current signals to the coils 60, 61 to enable limited operation of the valve slice so that the associated hydraulic fluid actuated device can be moved slowly to a safe position.

The operation of the failed valve slice by the recovery circuit allows only limited operation of the valve slice in so far as only closed loop control without position feedback of the two main spool valves is permitted, with the result that only pulse supply of fluid to the hydraulic fluid actuated device is possible in response to repeated joystick actuation by the operator. The recovery circuit pulses the pilot valves first in one direction to open the main spool valves and then in the other direction to close the main spool valves. Normally, however, the recovery circuit will not provide full position feedback control of the main spool valves in dependence on signals received from the position sensors 23 and 24 as would be provided under normal control operation of the valve slice, and will not therefore allow full operator control of the hydraulic fluid actuated device as provided under normal operation.

Although the control system is described above in relation to the control of an electrohydraulic proportional control valve assembly for controlling a hydraulic fluid actuated device, it should be appreciated that the control system may be used for controlling other types of control assembly, for example an electrical control assembly,

for the purpose of controlling other types of device, such as an electrical motor. It is envisaged that the control system could be used in a wide range of industrial control applications, for example in automated production or materials handling systems or in remote handling systems, such as robotic manipulators.

CLAIMS

1. An electronic control system for an electrohydraulic control valve assembly incorporating valve means for controlling the flow of hydraulic fluid to and from at least one hydraulic fluid actuated device, the control system comprising operating means adapted to be actuated by an operator to control the or each hydraulic fluid actuated device, system control means for monitoring operator actuation of the operating means and for outputting demand signals in response to such operator actuation, valve control means for controlling the valve means to control hydraulic fluid flow to and from the or each hydraulic fluid actuated device in dependence on the demand signals from the system control means, monitoring means for monitoring the valve control means and for producing an error signal in the event of a malfunction of the valve control means, and recovery means operative to accept demand signals from the system control means in the event of an error signal indicating a malfunction of the valve control means being produced by the monitoring means, and to effect limited actuation of the valve means to control hydraulic fluid flow to and from the or each hydraulic fluid actuated device in response to the demand signals to enable the or each hydraulic fluid actuated device to be placed in a recovery condition by the operator following such malfunction.

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2. A control system according to claim 1, for controlling hydraulic fluid flow to and from a plurality of hydraulic fluid actuated devices, wherein the valve control means comprises a respective valve control circuit associated with each hydraulic fluid actuated

device, each valve control circuit being adapted to control two main valves of the valve means for controlling hydraulic fluid flow to and from two ports of the associated hydraulic fluid actuated device, and wherein the recovery means comprises a respective recovery circuit associated with each hydraulic fluid actuated device and adapted to effect limited control of said two main valves to control hydraulic fluid flow to and from the two ports of the device in the event of a malfunction of the associated valve control circuit.

3. A control system according to claim 2, wherein each valve control circuit is adapted to effect positional control of the valve member of a respective pilot valve for controlling the flow of hydraulic fluid to and from each main valve, and each recovery circuit is adapted to effect limited control of the valve members of the pilot valves of the associated main valves in the event of a malfunction of the associated valve control circuit.

4. A control system according to claim 3, wherein each valve control circuit is adapted to supply position control signals to actuating coils of the pilot valves of the associated main valves, and each recovery circuit is adapted to supply recovery control signals to the actuating coils of the pilot valves of the associated main valves in the event of a malfunction of the associated valve control circuit.

5. A control system according to any preceding claim, wherein the monitoring

means is adapted to shut off the supply of selected control signals from the valve control means to the valve means in the event of a malfunction of the valve control means.

6. A control system according to any preceding claim, wherein the monitoring means is adapted to supply to the system control means an error signal indicating the identity of a valve control circuit of the valve control means in respect of which a malfunction has been detected.

7. A control system according to any preceding claim, wherein the valve control means is adapted to transmit regular identifying signals indicating the identity of a plurality of valve control circuits of the valve control means, and the system control means is adapted to monitor receipt of said identifying signals from the valve control means and to determine the identity of a valve control circuit which has failed by sensing that receipt of identifying signals from said valve control circuit has ceased.

8. A control system according to any preceding claim, wherein the system control means is adapted to supply to the recovery means a recovery initiation signal indicative of the identity of a valve control circuit of the valve control means which has failed in order to activate only the recovery circuit of the recovery means which is associated with the failed valve control circuit.

9. A control system according to claim 8, wherein the system control means is

adapted to communicate with the recovery means by way of two CAN bus wires.

10. An electronic control system for an electrohydraulic control valve assembly, substantially as hereinbefore described with reference to the accompanying drawings.

11. An electrohydraulic proportional control valve assembly incorporating an electronic control system according to any preceding claim.

12 An electronic control system for controlling at least one automated device, the control system comprising operating means adapted to be actuated by an operator to control the or each device, system control means for monitoring operator actuation of the operating means and for outputting demand signals in response to such operator actuation, device control means for controlling the or each device in dependence on the demand signals from the system control means, monitoring means for monitoring the control means and for producing an error signal in the event of malfunction of the device control means, and recovery means operative to accept demand signals from the system control means in the event of an error signal indicating a malfunction of the device control means being produced by the monitoring means, and to effect limited actuation of the or each device in response to the demand signals to enable the or each device to be placed in a recovery condition by the operator following such malfunction.

The Patent Office

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Application No:	GB 9621207.1	**Examiner:**	Mr Andrew Bartlett
Claims searched:	1-12	**Date of search:**	6 December 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G3N (NGK2B, NGK2A, NGK2)

Int Cl (Ed.6): G05B 9/02, 9/05, 23/00 & 23/02; F15B 13/043, 19/00 & 20/00; F16K 51/00 & 37/00;

Other: Online:- WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	GB 2103837 A (Mikuni Kogyo K.K.) See col 1 line 113 to col 2 line 14.	12

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.